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SECOND GENERATION COCONUT BIODIESEL: THE BEST BIODIESEL ALTERNATIVE TO DIESEL AS A FUEL IN A COMPRESSION IGNITION ENGINE

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ABSTRACT

The numerous experimental works carried out in the past on biodiesels have not come up with any conclusion on the best biodiesel that can replace diesel. Hence, the present work focuses on understanding the technical feasibility of coconut methyl esters (CME), palm methyl esters (PME) and sunflower methyl esters (SME) derived from used oil in a diesel engine. As physiochemical properties of the fuels influence their combustion and performance characteristics, an attempt to relate the properties to the performance is made. It can be concluded that not one property influences the efficiency, but the cumulative effect of all the properties does. Apparently, thermal efficiency can be slightly improved by using SME and CME than diesel, while PME yields least thermal efficiency among all, at all the loads. Though, it shows higher specific fuel consumption, its higher thermal efficiency and lesser NOx emissions justify the technical feasibility of CME as the best biodiesel that can replace diesel among PME, SME and CME at the given injection pressure and timing.

KEYWORD : Biodiesel, Performance; Combustion & Oxides of Nitrogen

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Original Article

INTRODUCTION

The energy required for the growth of any economy has been self sufficiently met by using the fossil fuels like diesel for the past few decades. The increase in fossil fuel consumption is leading to the depletion of fossil fuel sources and thus the need to search for an alternate emerges out. As an alternative, a lot of research on adding water to diesel is being carried out. But, it ended up in no conclusion due to the associated problems in turning it practical [Kiran Raj Bukkarapu et al, 2017a]. Vegetable oils are the most promising alternative [Xiaohu Fan et al, 2009] because they are not only renewable, but also easily available [Mert Gulum et al, 2017, Ekrem Buyukkayya et al, 2010]. Several attempts using peanut, palm, linseed, soyabean, rape seed and coconut oils directly in diesel engines were made by different researchers [Kiran Raj Bukkarapu et al, 2017b]. However, the results were not fruitful owing to the physiochemical properties of those oils which limited their usage. The transesterification process which turned a boon in reducing higher viscosities of vegetable oils, helped many in the production of methyl esters viz.,. biodiesel [Kiran Raj Bukkarapu et al, 2017c]. In transesterification, triglycerides are allowed to react with ethanol/methanol in the presence of a catalyst like NaOH/KOH and are converted to mono-glycerides [Demirbas, 1998], thus producing biodiesel.

Irrespective of the several attempts made by the different agencies across the world, biodiesel did not turn successful at commercial level due to its technical feasibility as compared to that of conventional diesel [Kaufman

KR et al, 1984, Kalam MA et al, 2002]. But in a country like India, where electric and hybrid vehicles are not affordable to major portion of the population, biodiesel still remains as a viable alternative. Alongside, good availability of oleaginous crops in India favors the research on biodiesel and its feasibility as a fuel in compression ignition engines.

Because of the fact that biodiesel can reduce human dependency on fossil fuels, green house emissions, its biodegradability and non toxicity, it can be considered as the best alternative to diesel [Xiaohu Fan et al, 2009, Amit Sarin, 2002]. But, the high cost of vegetable oils, especially edible oils, from which biodiesels are processed, rules out them in economic evaluation. This disadvantage can be countered by using non-edible oils or used/waste vegetable oils as feedstock to process biodiesel.

Numerous experiments carried out by different researchers have concluded that a diesel engine with biodiesel as fuel results in reduced power output alongside increasing the specific fuel consumption when compared to diesel. However, reduction in emissions of hydrocarbons (HC) and carbon monoxide (CO) is also reported [Atlin R et al, 1991]. Majority reports concluded that there will be increased NOx (oxides of nitrogen) on using biodiesel fuels. Carraretto C et al (2011) report that higher the biodiesel percentage in a blend with diesel, lower will be the power output of the engine. Lower emissions of CO, CO_2 and HC were observed by Labeckas G et al (2006) in their investigation with rapseed biodiesel in diesel engines. Chit Wityi Oo et al (2015) evaluated the performance of a diesel engine using diesel, jatophra methyl ester, coconut methyl ester, soybean methyl ester and palm methyl ester and concluded that ignition delay of all the biodiesel fuels are shorter than that of diesel while coconut methyl esters exhibit significant shortest ignition delay. An independent investigation on the relation between physiochemical properties of different biodiesels and their technical feasibility in compression ignition engines has not been carried out till date. Hence, the present work focuses on understanding the combustion characteristics of different biodiesels (which are influenced by their properties) and in concluding the biodiesel that can be a best alternative to diesel, among (second generation) sunflower methyl esters, coconut methyl esters and palm methyl esters.

MATERIALS AND METHODOLOGY

BIODIESEL PRODUCTION

One liter of three different fried/used oils, sunflower oil, palm oil and coconut oil were supplied by a local mess. The feedstock is heated to 90`C for around 20 minutes. To 15% of methanol, 1% of NaOH is added and agitated for 20 minutes at 700 rpm. This methoxide solution was added to the preheated oil and continuously agitated for nearly an hour. Then it is allowed to separate in a gravity separation flask for 8-10 hours. The glycerine formed is separated from the yield, the biodiesel and water washed to remove any traces of NaOH. Then the biodiesel is heated to about 100`C to remove the traces of moisture present, if any. The biodiesel yield from used coconut oil is termed as coconut methyl esters (CME), used palm oil is termed as Palm methyl esters (PME) and from used sunflower oil is termed as sunflower methyl esters (SME).

Physiochemical Properties

Kinematic viscosity is measured using Ostwald viscometer, according to ASTM D-445 where it is limited to 1.9-6.0 mm2/s at 40`C. There is no any ASTM method described or limit for density measurement. Density of the samples is determined using a 25ml pycnometer at 40`C and calorific value is measured as specified by ASTM, in Fuels lab of VFSTR University. The uncertainty for all the measurements is between 0.5% - 1.5% for three separate determinations.

Test Set Up

A constant speed and variable load test is conducted in a single cylinder four stroke computerized direct injection diesel engine. The specifications of the engine are tabulated as Table 1. Combustion analysis and data sampling is done using IC engine soft_9.0. The test engine is equipped with an eddy current dynamometer. The crank angle measurements are made using Kubler make 8.3700.1321.0360 crank angle sensor. In-cylinder, pressure measurements are communicated using IKA SL-1 pressure transmitter whose pressure ranges to 25MPa.

Table 1: Specifications of the Test Engine

S.No	Specifications Of The Test Engine	
1	Engine type	Four stroke Direct injection computerized diesel engine
2	Number of cylinders	1 no.
3	Bore	87.5 mm
4	Stroke	110 mm
5	Displacement	0.661 ltr
6	Compression ratio	17.5:1
7	Max. torque	33 Nm at full load
8	Max. power	5.2 kW at 1500 rpm
9	Injection timing	23deg CA bTDC

The experiments were conducted at a constant speed of 1500 rpm for different loads using diesel and methyl esters derived from used coconut, palm and sunflower oils. The fuel flow rate, cylinder pressure histories and exhaust gas temperatures are measured at different loads and the uncertainties in the measurements are 0.6, 0.6 and 1.4 % respectively. An uncertainty of 60 ppm is found in the measurements of NOx emissions.

RESULTS AND DISCUSSIONS

The results pertaining to performance and combustion characteristics of Coconut methyl esters (CME), palm methyl esters (PME), sunflower methyl esters (SME) in comparison to diesel are presented and discussed here.

Physiochemical properties

Waste coconut oil, waste palm oil and waste sunflower oil supplied by the university mess are used in processing the bio-diesels by transesterification and are characterized. Table 2 demonstrates the physiochemical properties of the processed methyl esters.

Table 2: Physiochemical Properties of the Processed Methyl Esters

S. No	Type of fuel	Kinematic viscosity at 40`C (mm^2/s)	Density at 40`C (kg/m^3)	Calorific value (kJ/kg)
1	Coconut methyl esters	2.65	823	35000
2	Palm methyl esters	4.60	850	37880
3	Sunflower methyl esters	4.90	829	37080
4	Diesel	2.60	830	42000

It is worthwhile to note that CME exhibits least viscosity that is close to diesel, with least energy content among all. On the other hand, CME also has the least density among all. SME is as dense as diesel at 40`C, but has lesser energy content relative to diesel. It also has the highest viscosity among all which is almost twice that of diesel. PME is the

densest among all, with higher energy content among the aforementioned biodiesel, but still lesser than that of diesel. Viscosity is a fuel property that influences spray atomization characteristics. Heating value of any fuel talks about the energy content and density about the mass of fuel consumed. Therefore, the varying properties of these different methyl esters would obviously have their influence on their combustion, emission and performance characteristics of the engine.

Performance Characteristics

To study the engine performance, several parameters like brake specific fuel consumption, brake thermal efficiency and torque generated when run on CME, PME, SME and diesel have been compared in the following sections.

Brake Thermal Efficiency (BTE)

With an intention of evaluating the engine performance, the thermal efficiency of the engine when run on different fuels is determined and plotted as Figure 1. It is observed from Figure 1. that the brake thermal efficiency of the engine is almost same upto 30% of load, when experimented on the four different samples. But above 30% load, the engine responds with thermal efficiencies in the decreasing order of SME, CME, Diesel and PME.

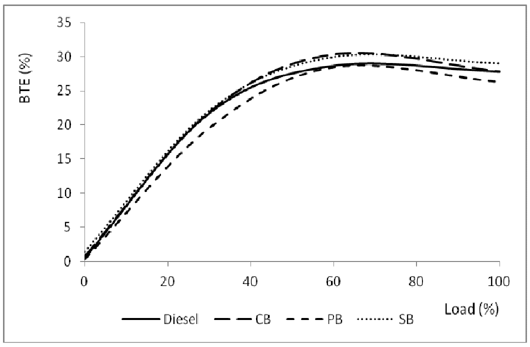

Figure 1: Variation of BTE With Load

The heat input given to the engine splits up into four ways which are heat equivalent to the power output produced, heat being taken away by the cooling water, heat being taken away by the exhaust gases and the radiation losses. Thermal efficiency talks about how good the heat input given to the engine is converted to the heat equivalent to power output, which would obviously be dictated by the fuel characteristics and hence this necessitates us to relate the fuel properties to the performance. As it can be seen from the Figure 1, CME and SME yield higher efficiency than diesel above 30% load while PME yields least thermal efficiency among all. Irrespective of the lesser energy content of CME than diesel and same kinematic viscosity, the thermal efficiency of the engine above 30% load is found to be slightly higher in case of CME which can be attributed to its oxygen bound nature. Apparently, though SME has twice the viscosity of diesel, same density and a lesser heating value, it is found to behave like CME in comparison with diesel, which can be due to its inbuilt oxygen. However, the oxygen bound nature of PME could not help it in yielding thermal efficiency higher than diesel due to its high density. It is an interesting observation that CME, with the least viscosity and SME, with the highest viscosity exhibited similar performance. CME has the least heating value which is ruled out by its least viscous nature in performing well. The high viscosity of SME might be dominated by its heating value in contributing to the thermal efficiency like CME. Therefore, it can be concluded that not one property influences the efficiency, but the cumulative effect of all the properties does and apparently thermal efficiency can be slightly improved by using SME and CME than diesel. It is interesting to note that the behavior of the engine's thermal efficiency follows the order of the torque produced. The torque generated by the engine with different fuels used is tabulated as Table 3.

Table 3: Torque Generated By the Engine When Tested on Different Fuels

Load (%)	Torque (N-m)			
	Diesel	CME	PME	SME
0	0.17	0.2	0.13	0.38
30	11.45	11.53	11.51	11.69
60	21.82	22.08	22.06	22.12
100	32.47	32.61	32.44	32.91

Brake Specific Fuel Consumption (BSFC)

It is a parameter reflecting engine performance in terms of fuel economy. As it can be observed from Figure 2, biodiesel lead to higher BSFC than that of diesel, which may be attributed to their lesser heating value. The oxygen content of the biodiesel pulls down their heating value resulting in higher fuel flow rate for a given power output of the engine. The engine responds with BSFC in the decreasing order of CME, PME, SME and diesel. For same power output, sample with lesser calorific value would obviously be consumed more. As a fuel is injected on a volume basis in a compression ignition engine, higher mass would be consumed in case of a denser fuel, for the same power output of the engine. The highest heating value of diesel is the obvious reason for its least consumption. It can be observed that BSFC of PME is higher because of its high density. Meanwhile, irrespective of similar densities CME is consumed more than SME owing to the fact that the earlier has lesser heating value than the latter. However, CME has the highest BSFC among all the fuels used and diesel the least.

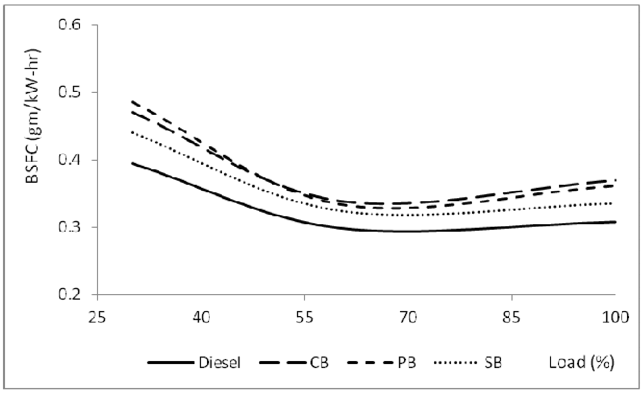

Figure 2: Variation of BSFC With Load

Combustion Characteristics

To analyze the combustion, heat release rates at different loads, combustion duration and maximum rate of pressure rise are determined and discussed in the following sections.

Heat Release Rate

It is important to determine the heat release rate to understand the fuel combustion characteristics. The heat release rates of all the fuels at different loads are compared in Figures 3-6. It can be observed that at no load condition, the heat release rate of all the fuels is almost same, except for PME (Figure 3). On increasing the load to 30%, the peak heat release rate has increased. The peak heat release rate for methyl esters is lower than that of diesel and is also advanced at 30% load (Figure 4). It seemed to get further more advanced for methyl esters as the load is increased to 60%, but still it is lower than that of diesel (Figure 5). The same trend can be observed at full load too. It is interesting to note that PME has well advanced heat release rate among all, at full load condition. The diffusion combustion of PME takes over its premixed

combustion at full load (Figure 6) owing to the reason that it is denser and so more PME is injected. But, due to its viscosity, the atomization of PME would be poorer and thus combustion occurs more due to diffusion than premixed, when compared to the remaining esters. This higher mass of fuel injected would also take more time for combustion, thus yielding in higher combustion durations. Figure 7 represents the mass flow rate of different fuels at different loads in which PME has the higher mass flow rate. At any load, PME is injected at higher rates owing to its density. The higher diffusion combustion heat release rate of PME signifies the importance of density of a fuel.

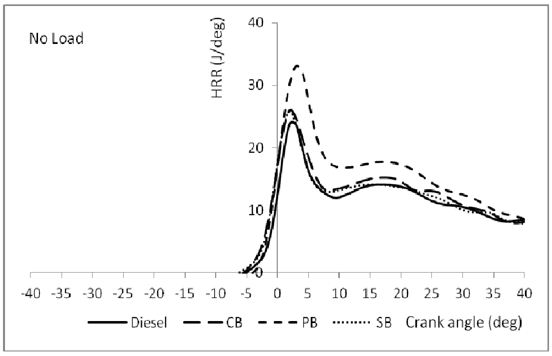

Figure 3: Heat Release Rate-Crank Angle Curve for Different Fuels at No Load Condition

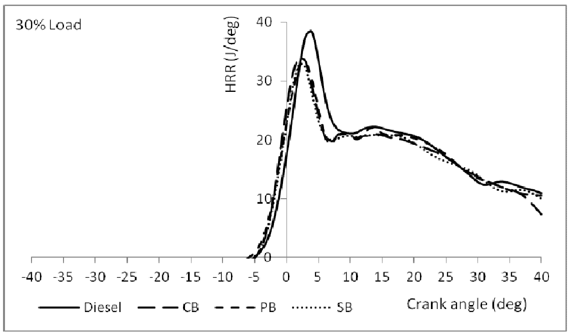

Figure 4: Heat Release Rate-Crank Angle Curve For Different Fuels At 30% Load Condition

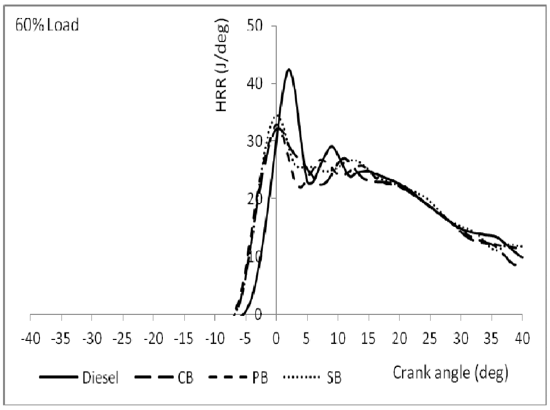

Figure 5: Heat Release Rate-Crank Angle Curve for Different Fuels at 60% Load Condition

However, at higher loads SME dominates the heat release rate among all the methyl esters which can be due to the disadvantages of other methyl esters like higher density of PME and lesser heating value of CME, when compared to SME. As load increases, it can be observed that SME tries to approach diesel in the heat release rate.

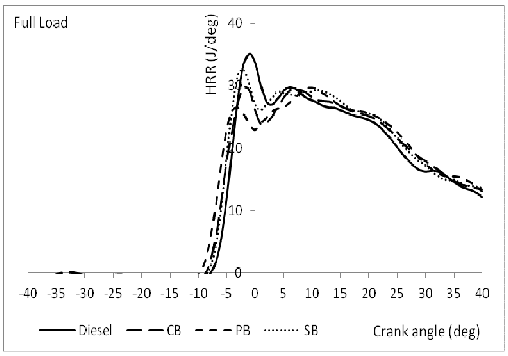

Figure 6: Heat Release Rate-Crank Angle Curve For Different Fuels at Full Load Condition

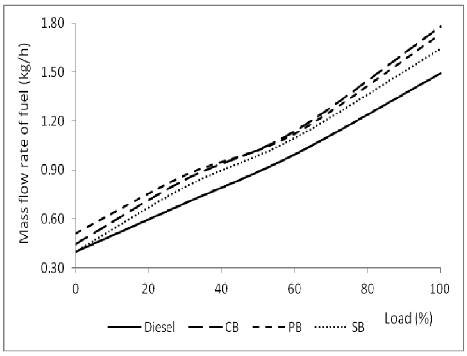

Figure 7: Fuel Flow Rate Versus Load

Combustion Duration

Figure 8 shows the comparison of combustion durations of all the fuels with the varying load. The crank angle where combustion is assumed to be ended corresponds to 90% of cumulative heat release. As the load increases, mass of the fuel injected into the cylinder increases along with the in-cylinder temperatures, which would help in quicker burning of the fuel thus reducing the combustion duration. It is obvious that fuel with lower viscosity (better atomization) and oxygen availability would burn at a quicker rate provided the in-cylinder temperatures are higher. Irrespective of the available oxygen content and similar viscosity CME takes more time for burning than diesel because of lesser in-cylinder temperatures, shown in Table 4. Higher mean gas temperature (MGT) of PME would be the obvious reason for its quicker burning when compared to CME. SME exhibits a combustion duration similar to diesel which can be the effect of oxygen content dominating its higher viscosity than that of diesel. This trend is observed only up to 60% load. While, above 60% load the cycle is too fast that the fuel will not be given sufficient time to burn properly. It is interesting to observe that even in such difficult situations CME burns quicker than the diesel owing to its oxygen content and higher mean gas temperature. Hence, it can be understood that the cumulative effect of viscosity and density, which influence atomization, mean gas temperature affects the combustion duration.

Table 4: Variation of Maximum Mean Gas Temperature With Load

Load (%)	Max MGT (`C)			
	Diesel	CME	PME	SME
0	1180.39	1142.00	1236.40	1111.96
30	1391.29	1349.50	1366.05	1328.20
60	1519.70	1506.98	1515.21	1544.70
100	1642.00	1650.50	1672.59	1685.87

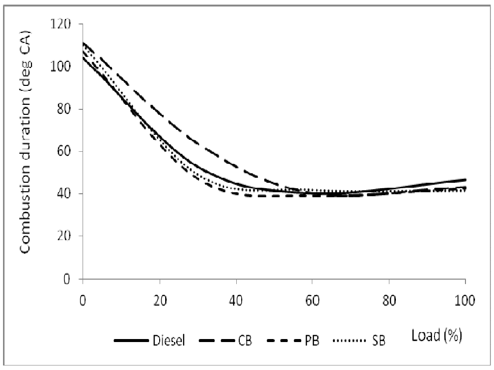

Figure 8: Variation of Combustion Duration of All the Fuels With Load

Maximum Rate of Pressure Rise

The smooth operation of the engine can be studied by understanding the rate of pressure rise. The maximum rate of pressure rise increases as the load on the engine is increased and at higher loads, it starts falling down slowly, which can be related to the dominance of diffusion combustion over premixed combustion, at higher loads. The max rate of pressure rise is lesser for biodiesel because of their lower certain numbers, as shown in Figure 9.

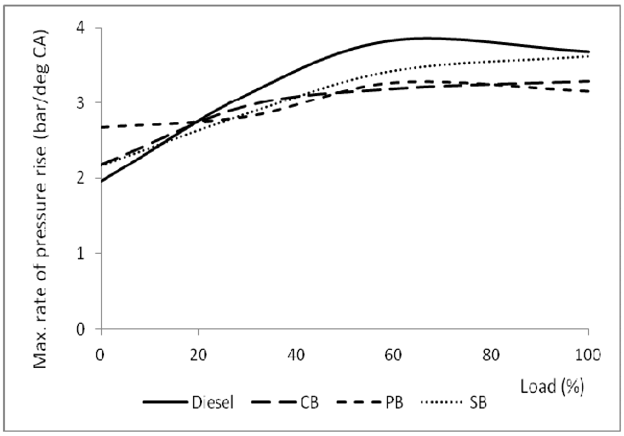

Figure 9: Variation of Maximum Rate of Pressure Rise with the Load

Emissions of Oxides of Nitrogen (NOx)

It is proved in the literature that NOx emissions are higher in case of bio-diesels, when compared to diesel which can be attributed to availability of oxygen to form nitric oxides on reacting with nitrogen at self sufficient temperatures. The inbuilt oxygen content which is a boon to biodiesel in its quicker and good combustion turns negative when it comes to NOx formation. However, it is found that SME has higher NOx emissions that PME and CME, as shown in Figure 10, which is in good correlation with the mean gas temperature shown in Table 4. CME has the least mean gas temperature at any load when compared to the other methyl esters and hence has least NOx emissions.

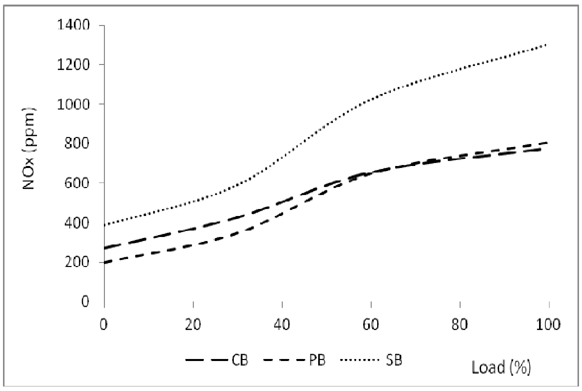

Figure 10: NO_x Emissions of Different Methyl Esters at Different Loads

CONCLUSIONS

The following conclusions have been drawn from the study.

- CME and SME yield higher efficiency than diesel above 30% load, while PME yields least thermal efficiency among all.
- It can be concluded that not one property influences the efficiency, but the cumulative effect of all the properties does and apparently thermal efficiency can be slightly improved by using SME and CME than diesel. PME at all loads shows an unacceptable behavior due to its poor physiochemical properties like high density and kinematic viscosity.
- Using SME is advantageous in terms of slight improvement in thermal efficiency of the engine, but at the cost of higher specific fuel consumption, higher NOx emissions relative to diesel. However, it is found to be better than PME in terms of specific fuel consumption and heat release rate. It is found to be superior to all the methyl esters used except for NOx emissions, which is dominated by CME.
- Owing to the least heating value, CME has highest specific fuel consumption among all the fuels. Irrespective of its higher specific fuel consumption, its behavior similar to SME and lesser NOx emissions than any other methyl esters justifies its technical feasibility as the best biodiesel than can replace diesel among PME, SME and CME at the given injection pressure and timing.

However, it is worthwhile to note that the conclusion drawn on CME being the best feasible methyl ester (considering both the performance and emission characteristics) is at a constant speed of 1500 rpm of the engine and deviations from the conclusion can be expected under different operating engine speeds.

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